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# THE EVALUATION OF POINT WEAR AND SAMPLE SHAPE ON POINT LOAD TEST INDICES

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## ABSTRACT

The point load index test provides a simple, effective means of deriving good first order approximations of rock strength parameters under field and/or laboratory conditions. In order to determine the effect of point wear and sample shape on the point load index calculated, samples of various shapes were tested using new points, points ground to simulate worn points, and points with sections cut from the tips to simulate chipped points. The samples were made of high strength concrete, the tensile and compressive strength of which was determined to be 5.75 MPa and 77.7 MPa respectively by the Brazilian (Indirect Tensile) test and uniaxial compressive strength testing.

Calculations showed that for all sample types, the average value for $I_{s54}$ determined using worn points was a factor of 0.70 higher than the value determined using the new points. It was also found that the average value for $I_{s54}$ determined using the chipped points was a factor of 1.38 lower than the $I_{s54}$ value determined using the new points.

The evaluation of the effect of sample shape was inconclusive.



## Résumé

Le test d'indice de charge ponctuelle constitue un moyen simple et efficace pour obtenir de bonnes approximations de premier ordre sur les paramètres de résistance d'une roche dans des conditions de laboratoire ou sur le terrain. Afin de déterminer l'effet d'usure ponctuelle et de la forme d'un échantillon sur l'indice de charge ponctuelle calculé, des échantillons de formes diverses ont été testés en utilisant des nouveaux points, des points de frottement pour simuler les points d'usure ainsi que des points avec des sections coupées de la pointe pour simuler les points effrités. Les échantillons étaient faits en ciment extrèmement résistant dont la force de compression et de traction, respectivement de 5.75 MPa et 77.7 MPa avait été déterminée par le test Brésilien (traction indirecte) et le test uniaxial de résistance à la compression.

Les calculs ont montré que pour tous les types d'échantillons, la valeur moyenne pour l'indice $I_{s54}$, déterminée en utilisant les points d'usure, avait un facteur 70% supérieur à la valeur déterminée en utilisant les nouveaux points. Il a été également trouvé que la valeur moyenne pour l'indice $I_{s54}$, déterminée en utilisant les points effrités, avait un facteur 138% inférieur à la valeur de l'indice $I_{s54}$ déterminée en utilisant les nouveaux points.

L'évaluation de l'effet de la forme de l'échantillon n'a pas été concluante.

## 1. INTRODUCTION AND OBJECTIVES

Rock strength is an important property, so a suitable strength-index test is desirable. The point load index test provides a simple, effective means of deriving good first order approximations of rock strength parameters under field and/or laboratory conditions. The Cape Breton Coal Research Laboratory (CBCRL) has undertaken a geotechnical research program to determine uniaxial compressive and tensile strength values of rock types encountered in the Sydney Coalfield. The strength parameters were derived from point load index tests conducted on both irregular lumps and core samples.

In the point load testing, conical platens are used to transmit a load through a sample. The point load index value is determined by dividing the breaking load by the square of the sample's diameter (distance between the platens). The final index values and, consequently, the rock strength values derived from it, can be influenced by the degree of point wear and the sample shape.

The main objective of the proposed project was to determine the effect of point wear and sample shape on the final point load strength indices and rock strength values obtained. After completing this, calculations were made to attempt to determine the nature and magnitude of any correction factors that must be made to enhance CBCRL's extensive data base of rock strength properties.

## 2. PROCEDURE

The testing undertaken by NSRFC was performed using an MTS materials testing machine. This is a 1,000 kN hydraulic machine with electronic control to provide controlled loading rates during the test. The MTS machine has a load measurement accuracy of $\pm$0.5%. The guide used to carry out testing was the CANMET Pit Slope Manual [1].

To determine the effect of the shape and size of the samples, it was necessary to find a material which had strength properties similar to the stone tested by CBCRL. It was determined that the material chosen for fabrication of the test samples should have a compressive strength of between 40 to 60 MPa. After testing several materials including various concretes (with different sand/cement and water to cement ratios), it was concluded that a concrete mixture with a composition of 35% sand, 49.2% cement, and a water to cement ratio of 0.32 would be most suitable for the testing program. The cement used was Portland Cement Type 30 high early strength manufactured by Canada Cement Lafarge. Initial testing of this material showed the material to have a compressive strength of approximately 50.4 MPa and the mixture flowed easily during pouring. Care was taken to remove as much air as possible during pouring of the concrete; the flowability of the mixture made this fairly easy. As the strength of concrete is affected by the curing conditions, all samples were held in a moist environment at approximately 70°F

for 28 days prior to testing.

Using this material, samples would be fabricated in four different shapes, regular cylinder with a length to diameter ratio (L/D) of 1.1; an irregular cylinder with an L/D ratio of 1.1; an irregular cubical sample with an L/D ratio of 1.1; and a larger cubical sample with an L/D ratio of 1.1, (but with D approximately 14% greater than for the previously-mentioned samples). The four sample types are shown in Figure 1, along with the compression testing sample and the specimen for the Brazilian (Indirect Tensile) tests.

Evaluation of the sample shape using irregular shapes required that these shapes be reproducible. After testing several materials, silicone rubber was selected as the most suitable mold material. Patterns for the selected irregular cubical, and irregular cylinder shapes were made from wood and plaster. These patterns were coated with wax to prevent adhesion, then coated with a thin layer of silicone rubber. Further layers of silicone were applied allowing time for curing in between, until the wall thickness of the silicone was sufficient to give a strong mold that had enough rigidity to give consistent shapes when concrete was cast in it, and still retain adequate flexibility for removal of the cured samples.

Several molds of each shape were fabricated so that production of samples could take place at a reasonable rate.

To measure the effect of point condition (wear or chipping), one set of points was ground to produce a greater radius at the platen contact surface with the samples. The second set of points had a section removed from the platen tip, leaving only about half of the tip intact. In this way, exaggerated wear and point chipping conditions respectively were simulated. Both these sets of platens are shown in Figure 2.

In the point load testing, the samples were measured to determine D (distance between platens) and L prior to testing. The measurement of D prior to the testing was taken as the value of D at fracture. This could be done because the specimens were hard, and the platens did not penetrate into the specimens [2]. The specimens were placed between the points, and loaded using the MTS system. The maximum load, (P), was recorded on the plotter of the system from the output of the load cell located in series with the loading ram and specimens.

To fully characterize the properties of the concrete samples used during this project, further tests were performed to determine the uniaxial compressive strength, modulus of elasticity, the tensile strength, and poisson's ratio ($\mu$), of the concrete.

The uniaxial compressive strength of the rock was determined by compressing a sample with an L/D ratio of approximately 2.7.

This test was performed by compressing the sample between flat steel plates, one of which incorporated a ball joint to ensure the samples were evenly loaded. During the compression, test data was collected on the axial strain by monitoring stroke, and on lateral strain using a circumferential extensometer. These values were used to calculate the modulus of elasticity and poisson's ratio for the concrete.

The tensile strength was calculated by using the equation:

$$\sigma_t = 2P / \pi Dt \qquad \text{Eq. 1}$$

given for the Brazilian (indirect tensile )test [3].

Both the uniaxial compressive strength and the tensile strength of the concrete were also calculated using the equations used by Aston et al. during the previous point load studies of the Cape Breton coal properties. [4]

Uniaxial Compressive Strength

$$\sigma_c = 29.24\ I_{s54} \qquad \text{Eq. 2}$$

Tensile Strength

$$T_s = 2.78 \quad I_{s54} \qquad \text{Eq. 3}$$

The value of $I_{s54}$ was calculated from the mean value of the point load index, I, using the same equation used by Aston et al. [4] and attributed to Hassan et al. [5]. This correction equation is:

$$\text{Log 10 } I_{s54} = 0.229 + \text{Log 10 } I - 1.008e^{-0.0274(D)} \qquad \text{Eq. 4}$$

The results of the tests described are included in Appendix A.

## 3. RESULTS

The values for the point load index ($I_s$) were determined and then corrected to an equivalent sample size of 54 mm using Eq. 4.

Table 1 shows the $I_{s54}$ values for all sample types and the different conditions of the three points.

**Table 1 Mean $I_{s54}$ (MPa)**

| Sample | Worn Point | New Point | Chipped Point |
|---|---|---|---|
| Regular Cylinder | 5.04 | 3.56 | 2.50 |
| Large Regular Cubical | 4.52 | 3.16 | 2.53 |
| Irregular Cylinder | 4.73 | 3.21 | 2.37 |
| Irregular Cubical | 4.25 | 3.07 | 2.06 |

A comparison of the data for each sample type showed that the values for the new, worn, and chipped points varied by statistically significant amounts. Because of this, we were able to calculate a multiplication factor for correction of the $I_{s54}$ values found using the worn and chipped points to an equivalent value using new points.

These correction factors are found in the following manner.

$C_w I_s$ = $I_s$ Corrected For Point Wear

$$C_w = \frac{I_{s54} \text{ NEW Pt.}}{I_{s54} \text{ WORN Pt.}}$$

$C_c I_s$ = $I_s$ (CORRECTED FOR POINT CHIPPING DAMAGE)

$$C_c = \frac{I_{s54} \text{ NEW Pt.}}{I_{s54} \text{ CHIPPED Pt.}}$$

Regular Cylindrical Sample

$C_w = \frac{3.56}{5.04} = .71$ $\quad$ $C_c = \frac{3.56}{2.50} = 1.42$

Irregular Cylindrical Sample

$C_w = \frac{3.21}{4.73} = .68$ $\quad$ $C_c = \frac{3.21}{2.37} = 1.35$

Irregular Cubical Sample

$C_w = \frac{3.07}{4.25} = .72$ $\quad$ $C_c = \frac{3.07}{2.06} = 1.49$

Large Regular Cubical Samples

$C_w = \frac{3.16}{4.52} = .70$ $\quad$ $C_c = \frac{3.16}{2.53} = 1.25$

Although the values of $I_{s54}$ for all sample types found using each point condition appear reasonably consistent, our analysis showed that there were statistically significant differences between $I_{s54}$ values.

The irregular cubical samples showed the greatest discrepancy to the other values. The comparison of the $I_{s54}$ values that showed significant differences are given in Table

2. The complete comparison of all values is given in Appendix B.

**Table 2**

| Samples Compared | Mean $I_{s54}$ (MPa) |
|---|---|
| Regular Cylinder, New Point | 3.56 |
| Irregular Cubical, New Point | 3.07 |
| Regular Cylinder, New Point | 3.56 |
| Large Regular Cubical, New Point | 3.16 |
| Regular Cylinder, Worn Point | 5.04 |
| Irregular Cubical, Worn Point | 4.25 |
| Regular Cylinder, Worn Point | 5.04 |
| Large Regular Cubical, Worn Point | 4.52 |
| Irregular Cubical, Worn Point | 4.25 |
| Large Regular Cubical, Worn Point | 4.52 |
| Regular Cylinder, Chipped Point | 2.50 |
| Irregular Cubical, Chipped Point | 2.06 |
| Irregular Cubical, Chipped Point | 2.06 |
| Large Regular Cubical, Chipped Point | 2.53 |

The tensile and uniaxial compressive strengths were calculated from the $I_{s54}$ values using equations 2 and 3 respectively. These strength values are given in Table 3.

Table 3

| Sample | Mean $I_{s54}$(MPa) | $T_c$(MPa) | $T_s$(MPa) |
|---|---|---|---|
| Regular Cylinder,Worn Point | 5.04 | 147.4 | 14.01 |
| Regular Cylinder,New Point | 3.56 | 104.1 | 9.9 |
| Regular Cylinder,Chipped Point | 2.50 | 73.1 | 7.0 |
| Large Regular Cubical,Worn Point | 4.52 | 132.2 | 12.6 |
| Large Regular Cubical,New Point | 3.16 | 92.4 | 8.8 |
| Large Regular Cubical,Chipped Point | 2.53 | 74.0 | 7.03 |
| Irregular Cylinder, Worn Point | 4.73 | 138.3 | 13.2 |
| Irregular Cylinder New Point | 3.21 | 93.9 | 8.9 |
| Irregular Cylinder,Chipped Point | 2.37 | 69.3 | 6.6 |
| Irregular Cubical,Worn Point | 4.25 | 124.3 | 11.8 |
| Irregular Cubical,New Point | 3.07 | 89.8 | 8.5 |
| Irregular Cubical,Chipped Point | 2.06 | 60.2 | 5.7 |

The tensile strength calculated for the material using the Brazilian Test showed a mean value of 5.75 MPa. The data collected from this testing is given in Appendix A.

The mean value of the uniaxial compressive strength of the concrete was determined to be 77.7 MPa. From the same series of tests the mean value of poisson's ratio was 0.152 at 40% of the ultimate load at failure, and the mean value of the modulus of elasticity was 18,150 MPa. The table of the complete results of the uniaxial compressive testing is given in Appendix A.

## 4. DISCUSSION

The material selected for fabrication of the test samples was 35% sand, 49.2% cement, and a water to cement ratio of 0.32. The preliminary testing of this material on samples of L/D approximately 1.1 and after seven days curing in a moist environment showed the compressive strength of the material to be 50.4 MPa. It was believed that an increase in the L/D ratio to 2.5-3.0 would give a compressive strength decrease and a longer curing time would give an increase in the compressive strength, resulting in no net change in the strength value. The actual uniaxial compressive strength of the concrete was shown to be approximately 77.7 MPa. Even though the compressive strength of the concrete was higher than anticipated, the difference in strength was probably not a detriment to the testing program. The most important factor affecting the results would be the uniformity of the concrete properties for all samples being tested, which in this project appeared adequate.

From the data collected from the point load testing, it appears that factors can be calculated to account for point wear and damage due to chipping. However, the factors calculated from the data collected in this project might be valid only for the point conditions used during the test. As stated earlier, and as seen in Figure 2, the point conditions are exaggerated a great deal, and it is unlikely that these would duplicate actual point conditions; therefore, the use

of the factors calculated is not recommended. What is clearly evident from this project, however, is that it is quite possible to correct point load data to the new point values by performing point load testing on materials with known properties using points with measured wear, and calculating correction factors.

The $I_s$ values for the point load tests were corrected to the equivalent $I_{s54}$ values. The mean values were then calculated for each sample type and point condition.

The estimation of the difference between the mean $I_s54$ values calculated was done using the equation:

$$(\bar{X}_1-\bar{X}_2)-t_{\alpha/2}\sqrt{\frac{S_1^2}{n_1}+\frac{S_2^2}{n_2}} < \mu_1-\mu_2 < (\bar{X}_1-\bar{X}_2)-t_{\alpha/2}\sqrt{\frac{S_1^2}{n_1}+\frac{S_2^2}{n_2}} \qquad \text{Eq.4}$$

where $\bar{X}_1$, and $S_1^2$ and $\bar{X}_2$ and $S_2^2$ are the means and variances of small independent samples of size $n_1$ and $n_2$ respectively from approximate normal distributions, and $t_{\alpha/2}$ is the value of the t distribution with

$$v = \frac{\{S_1^2\, n_1 + S_2^2/n_2\}^2}{[(S_1^2/n_1)^2/(n_1-1)] + [(S_2^2/n_2)^2/(n_2-1)]} \qquad \text{Eq. 5}$$

degrees of freedom, leaving an area of $\alpha/2$ to the right [5].

In all calculations, $t_{\alpha/2}$ was chosen for the 95% confidence interval.

In estimating the difference between two means, a significant difference between two means is established if the range of the difference does not include zero.

For example, we compared the mean of the $I_{s54}$ value for the regular cylinder samples tested with the new points to the mean of the irregular cubical samples tested with the new points. This showed with 95% confidence that the interval from 0.0591 to 0.9209 contains the true difference between the two means. As this interval does not include zero, the difference between the means is determined to be significant. We compared the mean of the $I_{s54}$ value for the regular cylinder tested with the new points to the irregular cylinder tested with the new points. This calculation showed with 95% confidence that the interval from -0.0731 to 0.7731 contains the true difference between the means. Because this interval includes zero, the actual difference between the two means could be zero, and so the difference is insignificant.

The results of the comparison of the $I_{s54}$ values of the different shaped samples was inconclusive. The large regular cubical sample appeared to differ slightly from the regular cylindrical and the irregular cubical samples, while the regular cylindrical samples did not differ significantly from

the irregular cylindrical samples. The extent of the correlation between all samples can be seen in the magnitude of the correction factors calculated as well as in the calculation of the difference between two means calculated and shown in Appendix B.

Caution must be used when using any of these findings to evaluate the effect of the shape of samples tested in the field. Accompanying the irregular shape is the possible presence of cracks and defects which are not accounted for in this project.

The tensile strength of the test material found by using the Brazilian test was significantly lower than the value calculated from $I_{s54}$ (New Point) using equation 3. The uniaxial compressive strength of the material found by compression testing was also significantly lower than the value calculated from $I_{s54}$(New Point) using equation 2.

The values for poisson's ratio and the modulus of elasticity were within the range expected for concrete [6].

## 5. CONCLUSIONS

Factors for correction of $I_{s54}$ values to "new point" values from data obtained using worn or chipped points were calculated; however, these factors are probably only valid in correcting data obtained using these specific points.

The calculation of correction factors was possible as significant differences between the values of $I_{s54}$ using the new, worn, or chipped points were noted.

The evaluation of the effect of the sample shape was inconclusive, but tended to show no difference between regular cylinder, irregular cylindrical, and large regular cubical samples. The large regular cubical samples had a D value approximately 14% greater than the smaller samples.

The irregular cubical samples with a D value similar to the smaller samples showed lower $I_{s54}$ values for all three point conditions.

Figure 1 Photograph of four sample types used in Point Load Testing along with compression testing and Brazilian Test Samples

Figure 2 Modified points to simulate worn and chipped points

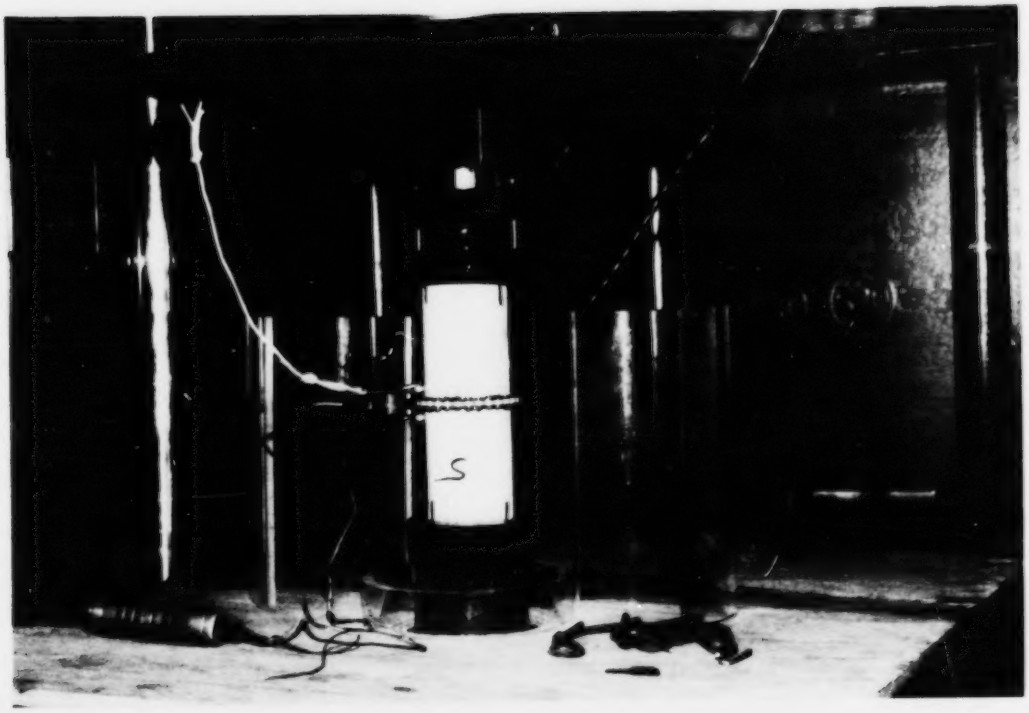

Figure 3 Set-up of apparatus used for Uniaxial Compressive Testing

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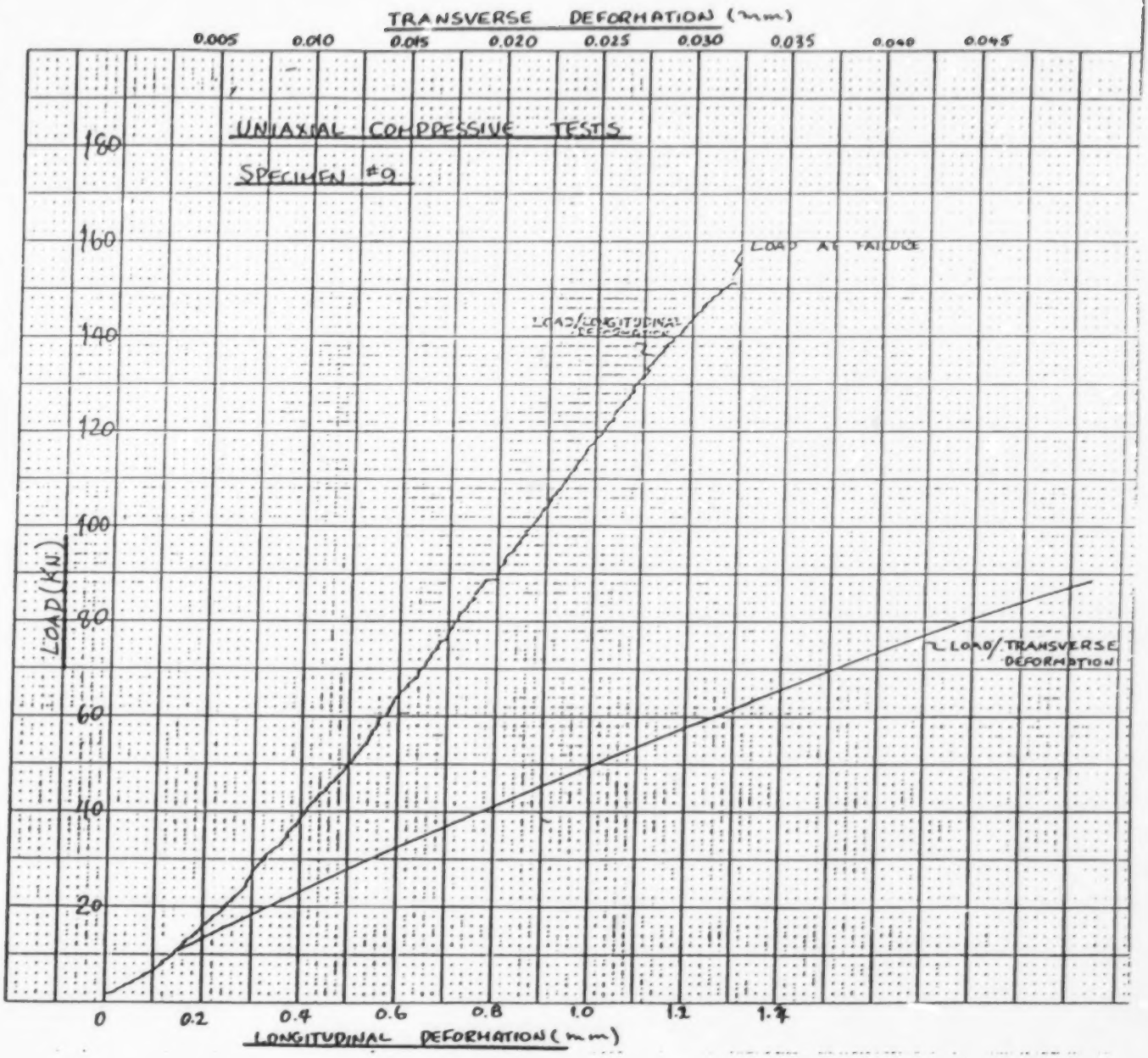
# APPENDIX A

LOAD VS. LONGITUDINAL DEFORMATION
AND
LOAD VS. LATERAL DEFORMATION



## UNIAXIAL COMPRESSIVE TESTING

| Specimen | Long. Strain At Failure | Poisson's Ratio At 40% U.L. | Modulus of Elasticity Slope from 20-40% of U.L. (MPa) |
|---|---|---|---|
| 2 | 0.00538 | 0.167 | 16,092 |
| 3 | 0.00531 | 0.134 | 14,908 |
| 4 | 0.00422 | 0.218 | 25,971 |
| 6 | ------- | ----- | ------ |
| 8 | 0.00467 | 0.101 | 20,364 |
| 9 | 0.00395 | 0.144 | 11,504 |
| 10 | 0.00364 | 0.149 | 20,060 |

| Specimen | Ultimate Load (kN) | Diameter D (mm) | Area ($mm^2$) | Compressive Strength (MPa) (Ultimate load/area) |
|---|---|---|---|---|
| 2 | 165.4 | 51.97 | 2,120.2 | 78.0 |
| 3 | 186.8 | 51.80 | 2,106.3 | 88.7 |
| 4 | 189.0 | 51.83 | 2,108.8 | 89.6 |
| 6 | 146.4 | 51.65 | 2,094.2 | 69.9 |
| 8 | 164.8 | 51.75 | 2,102.3 | 78.4 |
| 9 | 151.0 | 51.72 | 2,099.8 | 71.9 |
| 10 | 142.3 | 51.74 | 2,117.7 | 67.2 |

U.L. - Ultimate Load at Failure

**MEAN VALUES**

| | |
|---|---|
| Mean Longitudinal Strain at Failure | 0.00453 |
| Mean Posson's Ratio at 40% U.L. | 0.152 |
| Mean Modulus of Elasticity | 18,150 MPa |
| Mean Ultimate Load | 163.7 kN |
| Mean Diameter D | 51.8 mm |
| Mean Compressive Strength | 77.7 MPa |

## BRAZILIAN TESTS

## (Indirect Tensile)

| Sample | Load (L) (N) | Diameter (D) (mm) | Thickness (t) (mm) | Tensile Strength ($T_s$) (MPa) $T_s=2L/\pi Dt$ |
|---|---|---|---|---|
| 51 | 6,470 | 51.97 | 12.85 | 6.2 |
| 52 | 5,940 | 51.80 | 12.93 | 5.7 |
| 53 | 5,720 | 52.01 | 12.50 | 5.9 |
| 54 | 5,980 | 51.82 | 12.50 | 5.9 |
| 55 | 6,030 | 51.81 | 13.32 | 5.6 |
| 56 | 5,910 | 51.82 | 12.47 | 5.8 |
| 57 | 6,700 | 51.74 | 15.89 | 5.2 |
| 58 | 6,720 | 51.93 | 13.31 | 6.2 |
| 59 | 6,570 | 52.05 | 12.74 | 6.3 |
| 60 | 5,610 | 51.98 | 13.12 | 5.2 |

**MEAN VALUES**

| | |
|---|---|
| Mean Load | 6,165 N |
| Mean Diameter | 51.89 mm |
| Mean Thickness$_s$ | 13.16 mm |
| Mean Tensile Strength | 5.75 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Large Regular Cubical Samples, New Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| 1 | 65.18 | 10,500 | 4,248.4 | 2.47 | 2.84 |
| 2 | 63.73 | 10,510 | 4,061.5 | 2.59 | 2.93 |
| 3 | 62.92 | 11,650 | 3,958.9 | 2.94 | 3.29 |
| 4 | 64.36 | 12,130 | 4,142.2 | 2.93 | 3.33 |
| 5 | 63.42 | 12,200 | 4,022.1 | 3.03 | 3.41 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 63.92 mm |
| Mean Load | 11,398 N |
| Mean $I_s$ | 2.79 MPa |
| Mean $I_s54$ | 3.16 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Large Regular Cubical Samples, Worn Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| 6 | 62.69 | 15,900 | 3,930.0 | 4.05 | 4.52 |
| 7 | 64.31 | 16,100 | 4,135.8 | 3.89 | 4.42 |
| 8 | 64.11 | 16,750 | 4,110.1 | 4.08 | 4.63 |
| 9 | 63.83 | 16,000 | 4,074.3 | 3.93 | 4.45 |
| 10 | 65.84 | 17,100 | 4,334.9 | 3.94 | 4.56 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 64.16 mm |
| Mean Load | 16,370 N |
| Mean $I_s$ | 3.98 MPa |
| Mean $I_s54$ | 4.52 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Large Cubical Samples, Chipped Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| 11 | 64.11 | 10,200 | 4,110.1 | 2.48 | 2.81 |
| 12 | 64.64 | 8,550 | 4,178.3 | 2.05 | 2.34 |
| 13 | 64.14 | 7,800 | 4,113.9 | 1.90 | 2.16 |
| 14 | 65.86 | 9,290 | 4,337.5 | 2.14 | 2.47 |
| 15 | 64.47 | 10,530 | 4,156.4 | 2.53 | 2.88 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 64.64 mm |
| Mean Load | 9,274 N |
| Mean $I_s$ | 2.22 MPa |
| Mean $I_s54$ | 2.53 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Irregular Cubical Samples, New Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| C1 | 52.25 | 9,280 | 2,730.0 | 3.40 | 3.31 |
| C2 | 52.54 | 9,100 | 2,760.5 | 3.30 | 3.23 |
| C3 | 52.17 | 6,850 | 2,721.7 | 2.52 | 2.45 |
| C4 | 52.66 | 9,340 | 2,773.1 | 3.37 | 3.30 |
| C5 | 52.20 | 8,540 | 2,724.8 | 3.13 | 3.04 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 52.36 mm |
| Mean Load | 8,622 N |
| Mean $I_s$ | 3.14 MPa |
| Mean $I_s54$ | 3.07 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Irregular Cubical Samples, Worn Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| C6 | 53.90 | 11,410 | 2,905.2 | 3.93 | 3.92 |
| C7 | 54.44 | 11,650 | 2,963.7 | 3.93 | 3.95 |
| C8 | 53.96 | 13,820 | 2,911.7 | 4.75 | 4.74 |
| C9 | 53.38 | 12,300 | 2,849.4 | 4.32 | 4.28 |
| C10 | 53.22 | 12,500 | 2,832.4 | 4.41 | 4.35 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 53.78 mm |
| Mean Load | 12,336 N |
| Mean $I_s$ | 4.27 MPa |
| Mean $I_s54$ | 4.25 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Irregular Cubical Samples, Chipped Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| C11 | 54.56 | 6,320 | 2,976.8 | 2.12 | 2.13 |
| C12 | 51.67 | 6,080 | 2,669.8 | 2.28 | 2.20 |
| C13 | 52.26 | 5,220 | 2,731.1 | 1.91 | 1.86 |
| C14 | 53.68 | 6,120 | 2,881.5 | 2.12 | 2.11 |
| C15 | 52.66 | 5,660 | 2,773.1 | 2.04 | 2.00 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 52.97 mm |
| Mean Load | 5,880 N |
| Mean $I_s$ | 2.09 MPa |
| Mean $I_s54$ | 2.06 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Cylinder Irregular Samples, New Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| R1 | 54.99 | 10,040 | 3,023.9 | 3.32 | 3.36 |
| R2 | 55.46 | 8,510 | 3,075.8 | 2.77 | 2.82 |
| R3 | 58.87 | 9,320 | 3,465.7 | 2.69 | 2.87 |
| R4 | 58.28 | 10,870 | 3,396.6 | 3.20 | 3.39 |
| R5 | 51.85 | 10,070 | 2,688.4 | 3.75 | 3.63 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 51.89 mm |
| Mean Load | 9,762 N |
| Mean $I_s$ | 3.15 MPa |
| Mean $I_s54$ | 3.21 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Irregular Cylinder Samples, Worn Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| R6 | 53.56 | 14,950 | 2,868.7 | 5.21 | 5.17 |
| R7 | 60.23 | 15,090 | 3,627.7 | 4.16 | 4.51 |
| R8 | 59.30 | 14,170 | 3,516.5 | 4.03 | 4.32 |
| R9 | 57.49 | 13,580 | 3,305.1 | 4.11 | 4.31 |
| R10 | 54.77 | 15,880 | 2,999.8 | 5.29 | 5.34 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 54.72 mm |
| Mean Load | 14,734 N |
| Mean $I_s$ | 4.56 MPa |
| Mean $I_s54$ | 4.73 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Irregular Cylinder Samples, Chipped Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| R11 | 56.41 | 6,650 | 3,182.1 | 2.09 | 2.16 |
| R12 | 58.76 | 6,110 | 3,452.7 | 1.77 | 1.89 |
| R13 | 54.90 | 7,380 | 3,014.0 | 2.45 | 2.48 |
| R14 | 54.38 | 7,180 | 2,957.2 | 2.43 | 2.44 |
| R16 | 53.59 | 8,280 | 2,871.9 | 2.88 | 2.86 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 55.61 mm |
| Mean Load | 7,120 N |
| Mean $I_s$ | 2.32 MPa |
| Mean $I_s54$ | 2.37 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Regular Cylinder Samples, New Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| 12 | 57.20 | 11,820 | 3,271.8 | 3.61 | 3.77 |
| 13 | 58.55 | 11,540 | 3,428.1 | 3.37 | 3.58 |
| 14 | 58.81 | 11,100 | 3,458.6 | 3.21 | 3.42 |
| 15 | 57.80 | 11,100 | 3,340.8 | 3.32 | 3.49 |
| 16 | 57.45 | 12,240 | 3,300.5 | 3.71 | 3.89 |
| 17 | 57.85 | 12,240 | 3,346.6 | 3.66 | 3.85 |
| 18 | 57.95 | 10,400 | 3,358.2 | 3.10 | 3.27 |
| 19 | 57.62 | 10,820 | 3,320.1 | 3.26 | 3.42 |
| 20 | 59.13 | 10,690 | 3,496.4 | 3.06 | 3.28 |
| 21 | 58.11 | 11,470 | 3,376.8 | 3.40 | 3.59 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 58.05 mm |
| Mean Load | 11,342 N |
| Mean $I_s$ | 3.37 MPa |
| Mean $I_s54$ | 3.56 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Regular Cylinder Samples, Worn Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| 22 | 56.42 | 14,380 | 3,183.2 | 4.52 | 4.67 |
| 23 | 55.79 | 17,100 | 3,112.5 | 5.50 | 5.63 |
| 24 | 56.68 | 12,900 | 3,212.6 | 4.02 | 4.17 |
| 25 | 57.58 | 17,580 | 3,315.5 | 5.30 | 5.56 |
| 26 | 56.51 | 15,800 | 3,193.4 | 4.95 | 5.12 |
| 32 | 58.33 | 16,900 | 3,402.39 | 4.97 | 5.27 |
| 33 | 58.07 | 13,550 | 3,372.13 | 4.02 | 4.25 |
| 34 | 58.19 | 14,100 | 3,386.08 | 4.16 | 4.40 |
| 35 | 58.70 | 18,400 | 3,445.69 | 5.34 | 5.68 |
| 36 | 57.05 | 15,850 | 3,254.70 | 4.87 | 5.07 |
| 37 | 57.32 | 17,580 | 3,285.58 | 5.35 | 5.59 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 57.33 mm |
| Mean Load | 15,831 N |
| Mean $I_s$ | 4.82 MPa |
| Mean $I_s54$ | 5.04 MPa |

## POINT LOAD TESTING

**SAMPLE DESCRIPTION:** Regular Cylinder Samples, Chipped Point

| Specimen No. | D (mm) | P (N) | $D^2$ ($mm^2$) | $I_s$ (MPa) | $I_s54$ (MPa) |
|---|---|---|---|---|---|
| 27 | 56.85 | 8,310 | 3,231.9 | 2.57 | 2.67 |
| 28 | 58.79 | 7,680 | 3,456.3 | 2.22 | 2.37 |
| 29 | 58.44 | 8,170 | 3,415.2 | 2.39 | 2.54 |
| 30 | 57.77 | 7,600 | 3,337.3 | 2.28 | 2.40 |
| 31 | 58.88 | 8,170 | 3,466.9 | 2.36 | 2.52 |

**MEAN VALUES**

| | |
|---|---|
| Mean Specimen Diameter | 58.15 mm |
| Mean Load | 7,986 N |
| Mean $I_s$ | 2.36 MPa |
| Mean $I_s54$ | 2.50 MPa |

# APPENDIX B

## DIFFERENCE OF TWO MEANS

**NEW POINTS**

Reg.Cyl.New Pt. $I_{s54}$ $X_1$ = 3.56 $S_1$ = .2223 n = 10

to Irreg.Cyl.New Pt. $I_{s54}$ $X_2$ = 3.21 $S_2$ = .3532 n = 5

$-.0731 < \mu_1 - \mu_2 < .7731$

$\therefore$ No Significant Difference

Reg.Cyl.New Pt. $I_{s54}$ $X_1$ = 3.56 $S_1$ = .2223 n = 10

to Irreg.Cubical New Pt. $I_{s54}$ $X_2$ = 3.07 $S_2$ = .3610 n = 5

$.0591 < \mu_1 - \mu_2 < .9209$

Reg.Cyl.New Pt. $I_{s54}$ $X_1$ = 3.56 $S_1$ = .2223 n = 10

to Lg.Reg.Cubical New Pt. $I_{s54}$ $X_2$ = 3.16 $S_2$ = .2567 n = 5

$.0816 < \mu_1 - \mu_2 < .7184$

Irreg.Cyl.New Pt. $I_{s54}$ $X_1$ = 3.21 $S_1$ = .3532 n = 5

to Irreg.Cubical New Pt. $I_{s54}$ $X_2$ = 3.07 $S_2$ = .3610 n = 5

$-.3808 < \mu_1 - \mu_2 < .6608$

$\therefore$ No Significant Difference

Irreg.Cyl.New Pt. $I_{s54}$ $X_1$ = 3.21 $S_1$ = .3532 n = 5

to Lg.Reg.Cubical New Pt. $I_{s54}$ $X_2$ = 3.16 $S_2$ = .2567 n = 5

$-.4118 < \mu_1 - \mu_2 < .5118$

$\therefore$ No Significant Difference

Irreg.Cubical.New Pt. $I_{s54}$ $X_1$ = 3.07 $S_1$ = .3610 n = 5

to Lg.Reg.Cubical New Pt. $I_{s54}$ $X_2$ = 3.16 $S_2$ = .2567 n = 5

$-.5585 < \mu_1 - \mu_2 < .3785$

$\therefore$ No Significant Difference

**WORN POINTS**

Reg.Cyl.Worn Pt. $I_{s54}$ $X_1$ = 5.04 $S_1$ = .5760 n = 11

to Irreg. Cyl. Worn Pt. $I_{s54}$ $X_2$ = 4.73 $S_2$ = .4895 n = 5

$-.3221 < \mu_1 - \mu_2 < .9421$

∴ No Significant Difference

Reg.Cyl.Worn Pt. $I_{s54}$ $X_1$ = 5.04 $S_1$ = .5760 n = 11

to Irreg. Cyl. Worn Pt. $I_{s54}$ $X_2$ = 4.25 $S_2$ = .3354 n = 5

$.2943 < \mu_1 - \mu_2 < 1.2857$

∴ No Significant Difference

Reg.Cyl.Worn Pt. $I_{s54}$ $X_1$ = 5.04 $S_1$ = .5760 n = 11

to Lg.Reg.Cubical Worn Pt. $I_{s54}$ $X_2$ = 4.52 $S_2$ = .0844 n = 5

$.1288 < \mu_1 - \mu_2 < .9112$

∴ No Significant Difference

Irreg.Cyl.Worn Pt. $I_{s54}$ $X_1$ = 4.73 $S_1$ = .4895 n = 5

to Lg.Reg.Cubical Worn Pt. $I_{s54}$ $X_2$ = 4.52 $S_2$ = .0844 n = 5

$-.1253 < \mu_1 - \mu_2 < .5453$

∴ No Significant Difference

Irreg.Cubical Worn Pt. $I_{s54}$ $X_1$ = 4.25 $S_1$ = .3354 n = 5

to Lg.Reg.Cubical Worn Pt. $I_{s54}$ $X_2$ = 4.52 $S_2$ = .0844 n = 5

$-.5052 < \mu_1 - \mu_2 < .0348$

∴ No Significant Difference

Irreg.Cubical Worn Pt. $I_{s54}$ $X_1$ = 4.25 $S_1$ = .3354 n = 5

to Irreg. Cylindrical W.Pt. $I_{s54}$ $X_2$ = 4.73 $S_2$ = .4895 n = 5

$-1.0701 < \mu_1 - \mu_2 < .1101$

∴ No Significant Difference

**CHIPPED POINTS**

Reg.Cyl.Chipped Pt. $I_{s54}$ $X_1$ = 2.50 $S_1$ = .1202 n = 5

to Irreg. Cyl. Chipped Pt. $I_{s54}$ $X_2$ = 2.37 $S_2$ = .3645 n = 5

$-.3113 < \mu_1 - \mu_2 < .5713$

∴ No Significant Difference

Reg.Cyl.Chipped Pt. $I_{s54}$ $X_1$ = 2.50 $S_1$ = .1202 n = 5

to Irreg. Cyl. Chipped Pt. $I_{s54}$ $X_2$ = 2.06 $S_2$ = .1329 n = 5

$.2552 < \mu_1 - \mu_2 < .6248$

∴ No Significant Difference

Reg.Cyl.Chipped Pt. $I_{s54}$ $X_1$ = 2.50 $S_1$ = .1202 n = 5

to Lg.Reg.Cubical Chipped Pt. $I_{s54}$ $X_2$ = 2.53 $S_2$ = .3072 n = 5

$-.4093 < \mu_1 - \mu_2 < .3493$

∴ No Significant Difference

Irreg.Cyl.Chipped Pt. $I_{s54}$ $X_1$ = 2.37 $S_1$ = .3645 n = 5

to Lg.Reg.Cubical Chipped Pt. $I_{s54}$ $X_2$ = 2.53 $S_2$ = .3072 n = 5

$-.6516 < \mu_1 - \mu_2 < .3316$

∴ No Significant Difference

Irreg.Cubical Chipped Pt. $I_{s54}$ $X_1$ = 2.06 $S_1$ = .1329 n = 5

to Lg.Reg.Cubical Chipped Pt. $I_{s54}$ $X_2$ = 2.53 $S_2$ = .3072 n = 5

$-.8549 < \mu_1 - \mu_2 < .0851$

∴ No Significant Difference

Irreg.Cubical Chipped Pt. $I_{s54}$ $X_1$ = 2.06 $S_1$ = .1329 n = 5

to Irreg. Cyl. Chipped Pt. $I_{s54}$ $X_2$ = 2.37 $S_2$ = .3645 n = 5

$-.7561 < \mu_1 - \mu_2 < .1361$

∴ No Significant Difference